SIMULATION STUDY ON OPTIMIZING FOAM-ASSISTED-WATER-ALTERNATING GAS (FAWAG) PARAMETERS FOR REDUCING ASPHALTENE PRECIPITATION IN LIGHT OIL

By

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14305

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

DECEMBER 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

CHONG CHEW HWA

ABSTRACT

Enhanced oil recovery (EOR) had become a focus nowadays to maximize oil recovery from the well. One of the EOR methods is Foam-Assisted-Water-Alternating-Gas (FAWAG) injection which is an improved techniques developed from Water-Alternating-Gas (WAG) injection to provide better gas mobility control and preventing early gas breakthrough due to viscous fingering and gravity overriding. The presence of asphaltene in light oil reservoir can bring unwanted problems especially in the production stage affecting the inflow and tubing performance besides reduction in term of production. The objective of this project is to investigate the impact of FAWAG on asphaltene precipitation by controlling the FAWAG parameters; gas injection rate, water injection rate, surfactant concentration, WAG ratio and WAG cycle. The method employed in this dissertation is to perform simulation run using Eclipse300 on the FAWAG parameters in order to decide on the optimum parameters to control the precipitation of asphaltene. From the simulation, the optimum parameters of FAWAG injection is obtain successfully and it can be concluded that FAWAG performs better with the presence of asphaltene.

ACKNOWLEDGEMENT

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CHAPTER 1: INTRODUCTION

1.1 Project Background

Foam-Assisted-Water-Alternating-Gas (FAWAG) injection is an Enhanced Oil Recovery (EOR) method which uses surfactant or foaming agent to generate foam to enhance the sweep efficiency during Water-Alternate Gas (WAG) injection. The foam generated during FAWAG help to reduce the Gas Oil Ratio (GOR) in the production wells besides increasing the mobility control of gas flow preventing early break-through face by conventional WAG injection (Tunio & Chandio, 2012).

Asphaltene precipitation is a solid-like material formed upon the change in temperature, pressure or composition (Yarranton, 2000). Asphaltene will form precipitate when in contact with n-heptane or n-pentane. This asphaltene precipitate will affects the field operation especially during production and refining stage. In this paper, the best brine salinity for FAWAG injection on asphaltene precipitation will be investigated.

1.2 Problem Statement

Apshaltene precipitation can affect the petroleum industry as it is responsible for various unwanted blockage cases which disrupts the tubing and inflow performance (Hajizadeh, Ravari, Amani, & Shedid, 2008). The small fraction of asphaltene presence in light crudes will give more problems compared to heavy crudes with higher asphaltene content due to instability (de Boer, Lerrlooye, Eigner, & van Bergen, 1995; Creek, Buckley, & Wang, 2008).

The application of CO_2 gas injection will cause asphaltene precipitate to be formed as the stability of asphaltene in the crudes had been disturbed. The precipitates which are formed defeated the aim of CO_2 gas injection in assisting oil recovery from reservoir. In order to minimize the formation of asphaltene precipitate in light crudes, researches had been carried out by implementing various possible EOR techniques. This dissertation work focused on the optimization of FAWAG parameters in reducing the asphaltene precipitation in light oil. The parameters being studied include the water injection rate, gas injection rate, surfactant concentration, WAG cycle and WAG ratio.

1.3 Objective

The objectives of this simulation study are:

- To determine the effect of FAWAG technique towards asphaltene precipitation in light oil
- To investigate the best case FAWAG parameters to maximize the oil recovery

1.4 Scope of Study

The scope of the study for this project is to perform simulation runs using Eclipse300 on a built synthetic reservoir. This synthetic reservoir model is build based on the data set provided in Eclipse. The grid properties, asphaltene properties and rock properties are kept constant throughout the simulation runs. The project covers two main simulations which are FAWAG model and FAWAG with asphaltene model. Parameters that are being manipulated in the simulation runs are the gas injection rate, water injection rate, surfactant concentration, WAG ratio and WAG cycle. Time frame allocated to conduct this project is approximately four (4) months. The research done is limited only to simulation work using Eclipse simulator and there is no laboratory work involved.

CHAPTER 2: LITERATURE REVIEW

2.1 Enhanced Oil Recovery (EOR)

EOR (also known as tertiary recovery), plays an important role in improving total production of a reservoir. Unlike the primary and secondary recovery, EOR targets the immobile oil which cannot be produced due to viscous forces and capillary (Kokal & Al-Kaabi, 2010). However, the implementation of EOR is highly related with the oil prices as well as the global overall economics.

2.2 Carbone Dioxide (CO_2) Injection

CO_2 injection is a common oil recovery technique which is largely practiced in the industry due to its cheap operating cost and taxes exclusion which benefits the overall project cost. This CO_2 injection technique can be subdivided into two categories which are miscible and immiscible flooding. In miscible injection, the injected gas swells the oil and at the same time reducing the oil viscosity and residual oil saturation (Martin & Taber, 1992; Ghedan, 2009; Sima, Omar, Alta'ee, & Hani, 2011) . The miscibility property of this injection will cause composition changes and caused the asphaltene to become unstable which will then result in the precipitation of asphaltene (Kokal & Sayegh, 1995; Ghedan, 2009).

2.3 Water-Alternate-Gas (WAG)

Water-Alternate-Gas injection method is a mature technology which had been widely implemented in North Sea, Canada and US oil fields. As the name suggest, WAG is an EOR method which involve the alternate injection of gas followed by water into the reservoir repeatedly. It is the common practice used to control the gas mobility in a reservoir and to lowers the reservoir producing GOR (Mangalsingh & Jagai, 1996; Dong, Foraie, Huang, & Chatzis, 2005).

This EOR technique gives a better sweep efficiency and hence increases the recovery of the reservoir (Dehghan, Farzaneh, Kharrat, Ghazanfari, & Rashchian, 2009). Besides that, many research suggested that WAG injection increases the microscopic gas displacement efficiency as well as the macroscopic water sweep efficiency as compared to the gas or water injection techniques (Christensen, Stenby, & Skauge, 2001; Dehghan, Farzaneh, Kharrat, Ghazanfari, & Rashchian, 2009).

Factors that affect the WAG injection process includes the reservoir heterogeneity, rock wettability, fluid properties, injection techniques, miscibility conditions, gas trapped, slug size, cycling frequency, injection rate and WAG ratio (Sanchez, 1999).

2.4 Foam-Assisted-Water-Alternate- Gas (FAWAG)

FAWAG injection technique is the improvement method from WAG. In FAWAG, foam generating agent (surfactant) is injected into the reservoir to generate foam for a better oil recovery performance. The foam generated in this technique increases the gas mobility control and prevent early breakthrough as observed in WAG.

The implementation of FAWAG is usually after WAG being introduced. It is observed that during WAG injection, the injected gas will rise to the top relatively quick leading to early breakthrough (Tunio & Chandio, 2012). Thus, FAWAG is meant to create a foam barrier preventing the gas to move upwards and forcing the gas to go through low permeability zones of the reservoir and hence increase the sweep efficiency (Al-Mossawy, Birol Demiral, & Raja, 2011; Tunio & Chandio, 2012).

Full-scale field demonstration of FAWAG is carried out in the Snorre field. This FAWAG treatment has been estimated to contribute approximately 250 000Sm^3 of oil with every $1 million spent (Blaker, Aarra, Rasmussen, Celius, Martinsen, & Vassenden, 2002). It is also observed in the project that FAWAG injection is capable to delay the premature gas breakthrough besides reducing the producing GOR in the reservoir.

2.4 Surfactant

Surfactant is an organic compound with the ability to alter the interfacial and surface properties besides capable to solubilise and self-associate in micelles (Schramm, Stasiuk, & Marangoni, 2003). It can be classified into four main classes which are anionic, cationic, non-ionic or amophoteric referring to the existence of charged hydrophilic groups.

The properties that a proper surfactant should have includes the ability to generate ample and lasting foam at reservoir condition, capable to increase the sweep efficiency and oil recovery of a reservoir, low decomposition losses and adsorption, and lastly it should inexpensive and commercially available (Casteel & Djabbarah, 1988).

2.5 Foam

Foam is defined as dispersion of gas in liquid as the gas mix with the surfactant solution. It can be generated in reservoir by continuous co-injection of surfactant solution and gas, or alternative injection of surfactant solution slugs and gas (Salehi, Safarzadeh, Sahraei, & S.A.T., 2013). It contains liquid films (lamellae) and Plateau borders with a connection point of lamellae at angle of 120° (Vikingstad, 2006).

The main usage of foam in the process of oil recovery is to control gas mobility and to reduce the GOR at the production well. The existence of foam in porous media will affects the diffusivity mechanism of the normal gas-liquid flow by trapping foam in the liquid lamellae and reduce the gas velocity which will then lead to stable foam condition (Al-Mossawy, Birol Demiral, & Raja, 2011).

2.6 Asphaltene

Asphaltene is a component in the crude oils which has high molecular weight and is soluble in n-heptane (Ruksana Thawer, 1990; de Boer, Lerrlooye, Eigner, & van Bergen, 1995). In the crude oil, asphaltene is stabilized by resin forming miscelles. The repulsive forces between the resin absorbed on asphaltene surface make this miscelle stable and will not flocculate (Thou, Ruthammer, MUL, Potsch, & OMV, 2002; Alta'ee, S.Hun, Alian, & Saaid, 2012).

The presence of asphlatene in crude oil will not bring any harm but asphaltene precipitation will bring unwanted blockage and flow assurance problem as it tends to occur in tubing, flow lines and surface facilities (Mohammed, Arisaka, & Kumazaki, 1998). In addition to blockage, this precipitation can cause formation damage such as reservoir plugging and wettability reversal (Hajizadeh, Ravari, Amani, & Shedid, 2008).

The factors that affect the stability of asphaltene include composition of the surrounding fluid, pressure and temperature (Eduardo, Lira-Galeana, Gil-Villegas, & Wu, 2004). The fluid composition of a reservoir can be change by operation such as gas injection and incompatible chemicals which will then affects the stability of asphaltene.

2.6.1 Asphaltene Stability Factor

The performance of crude oil will be affected by the asphaltene precipitate. A small fraction of asphaltene in light oil is more likely to be problematic compared to heavy oil with higher fraction of asphaltene (de Boer, Lerrlooye, Eigner, & van Bergen, 1995). This phenomenon can lead to issue such as reservoir plugging. Therefore, it is important to ensure asphaltene is in stable state as it will directly affect the reservoir performance. The stability of asphaltene is dependent three (3) main factors which are pressure, temperature and composition of the surrounding fluid (Ruksana Thawer, 1990).

Factor 1: Pressure

Change in pressure due to fluid injection can alter the equilibrium state of reservoir fluid in the reservoir which can lead to precipitation of asphaltene. The asphaltene onset pressure (AOP) is the pressure where the asphaltene started to form at constant temperature in live reservoir fluid. In lower reservoir pressure, a lower asphaltene solubility is observed (Verdier, Carrier, Andersen, & Daridon, 2005; Sima, Omar, Alta'ee, & Hani, 2011).

As pressure decreases from higher point from bubble point pressure, density of the oil is reduced and this increases the molecular mass of the reservoir fluid (Hun, 2012) . Maximum asphaltene precipitation is observed at bubble point pressure where the highest molecular mass difference between bulk oil and asphaltene is observed (Hun, 2012). Further pressure drop in lighter hydrocarbon, the asphaltene solubility with resin decreases and resulted in precipitation of asphaltene (Kokal & Sayegh, 1995; Mohammed, Arisaka, & Kumazaki, 1998; Afshari, Kharrat, & Ghazanfari, 2010; Alta'ee, S.Hun, Alian, & Saaid, 2012; Hun, 2012).

Factor 2: Temperature

Disagreements are found between researchers on the relationship between temperatures on asphaltene precipitation. Temperature observed will increase when there is a reduction of asphaltene precipitation (Nghiem, Kohse, Maeda, & Ohno, 2000). However, the research by Burke *et al* (1990) proved the opposite.

On the other hand, asphaltene is observed to be less stable when the temperature decrease resulted from the energy differences between the crude oil molecules and asphaltene (Verdier, Carrier, Andersen, & Daridon, 2005).

Factor 3: Surrounding Fluid Composition

Asphaltene stability is also influence by its surrounding fluid composition. Activity such as gas injection can alter the phase equilibrium and the asphaltene solubility parameters in the crude oil (Kokal & Sayegh, 1995). The injection of gas into the reservoir alters the amount of resin available to stabilize the asphaltene in the crude and hence lead to the formation of precipitate (Mohammed, Arisaka, & Kumazaki, 1998). Miscible solvent have the capacity to triggers asphaltene instability. Toe most effective solvent which can resulted in asphaltene precipitation is CO_2 followed by alkanes (Gholoum, Oskui, & Salam, 2003).

2.8 Summary of Literature Review

EOR is a technique aiming to produce the immobile oil in the reservoir. Miscible CO_2 injection swells the oil and reduces the oil viscosity and residual oil in the reservoir. However, this type of injection will change the composition of the fluid and caused the asphaltene in the fluid to become unstable resulting in the formation of asphaltene precipitate. On the other hand, WAG injection which involves alternate injection of gas followed by water in certain ratio into the reservoir. It targets to control gas mobility. Nevertheless, premature gas breakthrough is observed during the application of this technique. To solve this issue, FAWAG is being introduced. In FAWAG, surfactant solution will be added into the reservoir. This surfactant will generate foam when in contact with the gas injected. Foam will block the higher permeability zone in the reservoir, pushing the gas injected to flow downwards to the low permeability zone and hence effectively solve the early gas breakthrough problem face in the WAG. Asphaltene is a component in crude oils with high molecular weight. The deposition of asphaltene occurs when there are alterations in reservoir pressure, temperature and fluid composition. This apshaltene precipitate can cause blockage in pipelines in some cases wettability reversal reducing the oil recovery.

CHAPTER 3: METHODOLOGY

There are several steps involved in order to complete the research. In the early stage, information on FAWAG method and asphaltene deposition is gathered by analyzing variety of works by scholars and researchers. With sufficient background information and knowledge on the project, a synthetic reservoir model is built and the fluid properties of the reservoir are defined. The data used for all the simulations are synchronized. In this project, most of the data included are based on the dataset available in Eclipse. A total two (2) simulations is carried out which are first on the FAWAG model without asphaltene followed by FAWAG model with asphaltene. The simulation is repeated again by manipulating the parameters which are gas injection rate, water injection rate, surfactant concentration, WAG ratio and WAG cycle. The FOPT result obtained from each simulation will be studied. Simultaneously, the optimum parameters will be observed and recorded.

Table 1: Optimization of gas injection rate

No.	Gas Injection Rate, scf/day	Field Oil Production Total (FOPT), stb	
		Without Asphaltene	With Asphaltene
1	50,000		
2	80,000		
3	100,000		
4	150,000		
5	200,000		

Table 2: Optimzation of water injection rate

No.	Water Injection Rate, stb/day	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	5,000		
2	10,000		
3	30,000		
4	65,000		
5	80,000		
6	100,000		

Table 3: Optimization on surfactant concentration

No.	Surfactant Concentration, lb/stb	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	0.001		
2	0.01		
3	0.1		
4	0.2		

Table 4: Optimization on WAG ratio

No.	WAG Ratio	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	1 : 0.65		
2	1 : 1		
3	1 : 2		
4	2 : 1		

Table 5: Optimization on WAG cycle

No.	WAG Cycle Time, days	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	30 : 70		
2	50 : 50		
3	70 : 30		

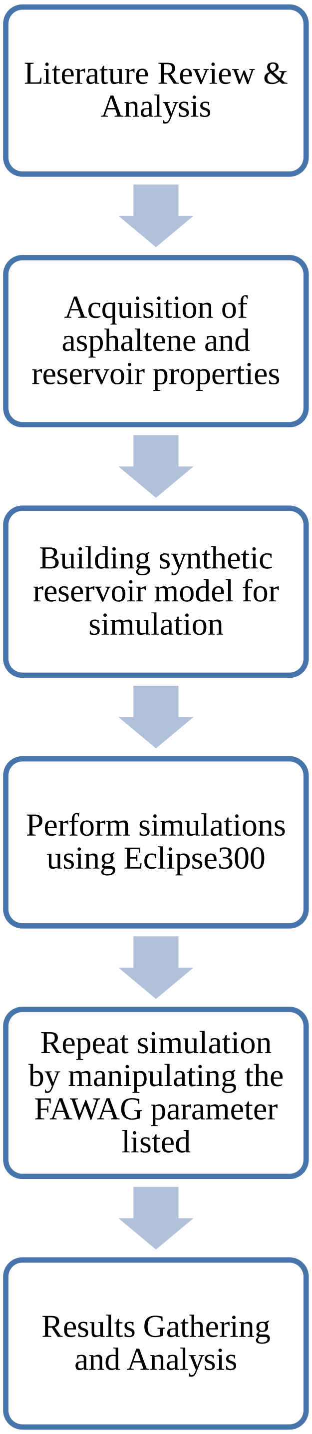


Figure 1: Methodology Flowchart

3.1 Reservoir and Fluid Properties

Table 6: Reservoir and Fluid Properties

Properties	Value
Reservoir Dimension	10*10*3
Number of Components	7
Thickness in x-direction	100 ft
Thickness in y-direction	100 ft
Thickness in z-direction (First Layer)	20 ft
Thickness in z-direction (Second Layer)	30 ft
Thickness in z-direction (Third Layer)	50 ft
Permeability in First Layer	500 mD
Permeability in Second Layer	50 mD
Permeability in Third Layer	200 mD
Density of Oil	49.1 lb/scf
Density of Water	62.4 lb/scf
Density of Gas	0.06054 lb/scf
Porosity	0.3
Depth of Oil-Water Contact	8500 ft
Depth of Gas-Oil Contact	8200 ft
Bottom Hole Pressure	1000 psia
Reservoir Pressure	4800 psia
Well Diameter	0.5 ft
Producer Well Location	(10,10,3)
Injector Well Location	(1,1,1)

3.2 Initial Reservoir Oil Components

Table 7: Initial Reservoir Oil Components

Components	Percentage %
C1	0.500
C3	0.060
C6	0.000
C10	0.200
C15	0.150
C20	0.090
Asphaltene	0.000

3.3 Injection Mechanisms

In this project, the model is simulated to undergo gas injection for 730 days before starting the FAWAG process. In the FAWAG process, water-surfactant solution and gas is injected simultaneously in a ratio of 1 : 0.65 for 2100 days. Once the cycle completed, the reservoir will once again flooded with gas for 5000 days.

Table 8: Injection mechanism for the base model

No. of Cycle	Injection Period (Days)	Injected Fluid	Injection Rate, scf/day(gas); stb/day(water-surfactant);
1	730	Gas	100,000
21	30 70	Water-Surfactant Gas	65,000 100,000
1	5000	Gas	100,000

3.4 Project Activities

The figure below illustrates the project activities:

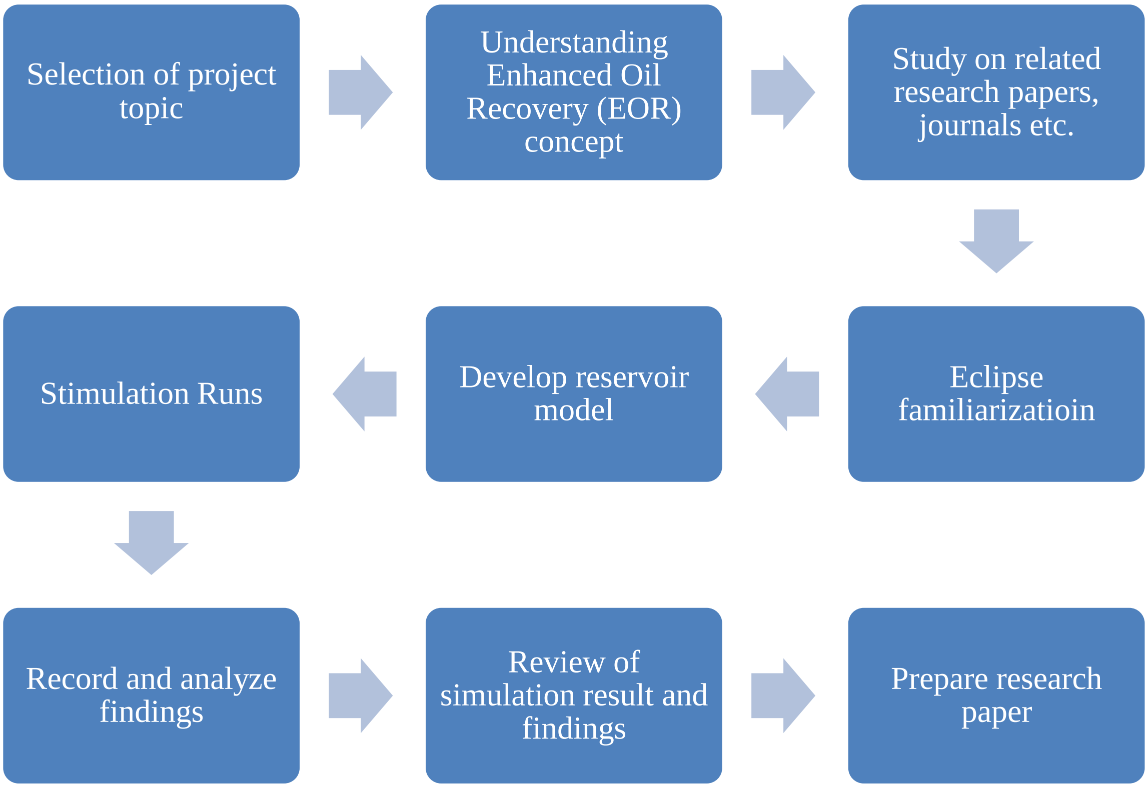


Figure 2: Project activities

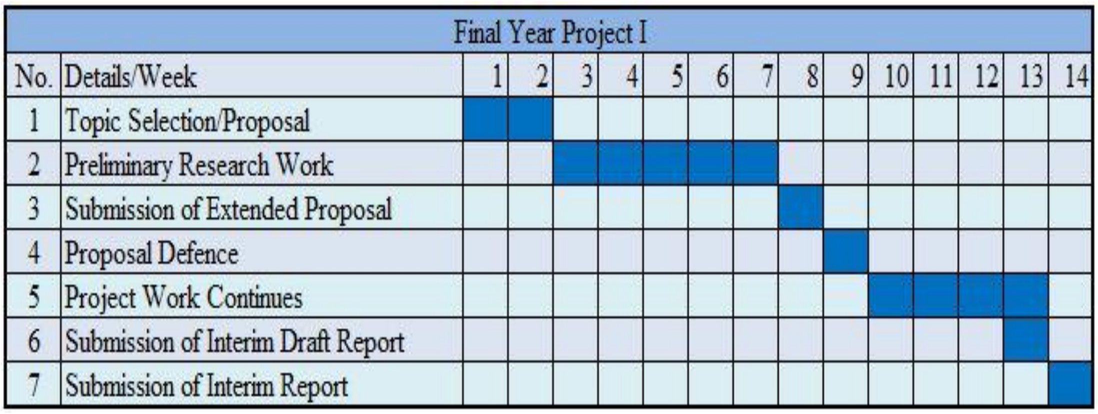
3.5 Project Key Milestones

Throughout the project, there are few significant key milestones. Each of these key milestones will further lead the author in carrying out her project. The major key milestones are illustrated as below:

Table 9: Key Milestone

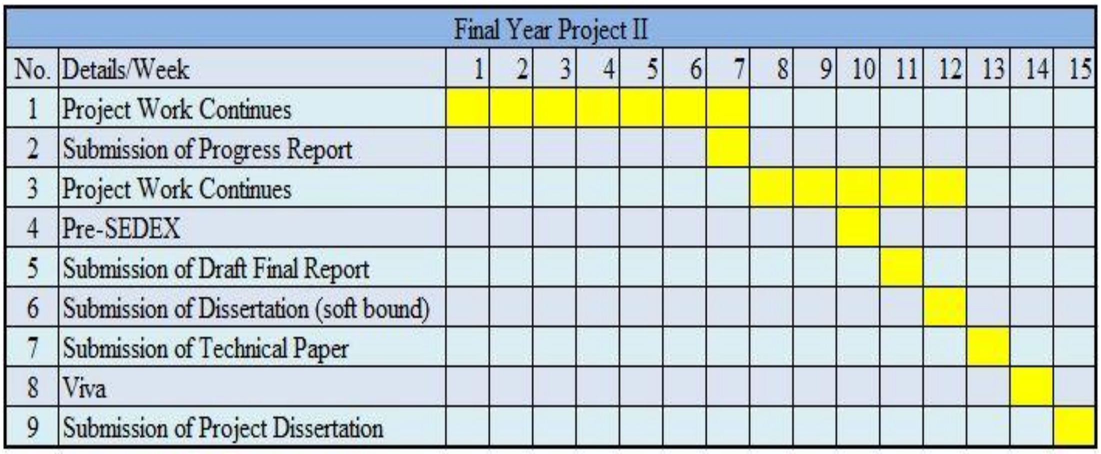
Project Activities	September	October	November	December
Familiarize with Eclipse	2 weeks			
Building Reservoir and Fluid Model		1 month		
Submission of Progress Report			5^{th} November	
Simulation started with WAG and FAWAG model without Asphaltene			1 month	
Simulation continue with WAG and FAWAG model with Asphaltene			1 month	
Result Compilation and Report Writing			1 month	
Pre-Sedex				Week 12
Draft Report Submission				Week 12
Dissertation Submission (Soft Bound)				Week 12
Technical Paper Submission				Week 12
Oral Presentation				Week 13
Project Dissertation Submission (Hard Bound)				Week 15

3.6 Grantt Chart



Final Year Project I															
No.	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection/Proposal														
2	Preliminary Research Work														
3	Submission of Extended Proposal														
4	Proposal Defence														
5	Project Work Continues														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

Figure 3: Grantt Chart FYP 1



Final Year Project II																
No.	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues															
2	Submission of Progress Report															
3	Project Work Continues															
4	Pre-SEDEX															
5	Submission of Draft Final Report															
6	Submission of Dissertation (soft bound)															
7	Submission of Technical Paper															
8	Viva															
9	Submission of Project Dissertation															

Figure 4: Grantt Chart FYP 2

CHAPTER 4: RESUTLS AND DISCUSSION

4.1 FAWAG without and with Asphaltene

<u>Keyword</u>

FOPT : Field Oil Production Rate

<u>Legends</u>

FAWAG without Asphaltene

FAWAG with Asphaltene

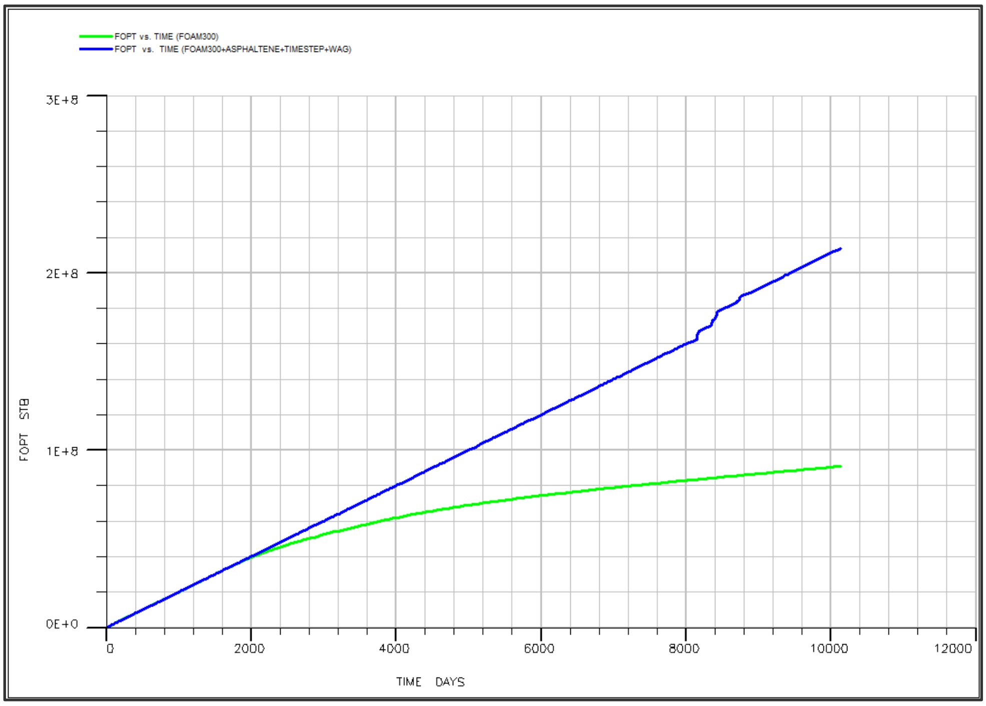


Figure 5: Comparison of FAWAG model (without and with asphaltene)(FOPT vs. time)

Based on the result in Figure 5 above, it is observed that FAWAG model with asphaltene content recover more oil as compared to FAWAG model without asphaltene content. The gas injected into the reservoir tends to travel upwards due to variation in permeability across the layers and gravity segregation. When the injected gas comes into contact with oil, asphaltene precipitation started to form. According to (Alta'ee A. , 2009), the deposition of asphaltene is being triggered when mixing gas with the asphaltene-presence crude. When CO_2 injection started, asphaltene precipitation is induced more as the gas swells the oil and lighter components in the reservoir and depreciated the solubility of asphaltene. This injected gas will travel to the higher permeability zones in order to escape out of the reservoir causing more asphaltene to precipitate at the upper layer zone with a higher permeability. The layer of precipitated asphaltene on top of the layer will force the injected gas to travel down to zone with lower permeability and sweep the oil contained in the area. At the same time, the presence of foam provides a better gas mobility control which helps to increase the oil recovery from the reservoir.

4.2. Comparison of Gas Injection Rate in FAWAG Model (without and with)

50000 SCF/Day

65000 SCF/Day

80000 SCF/Day

150000 SCF/Day

200000 SCF/Day

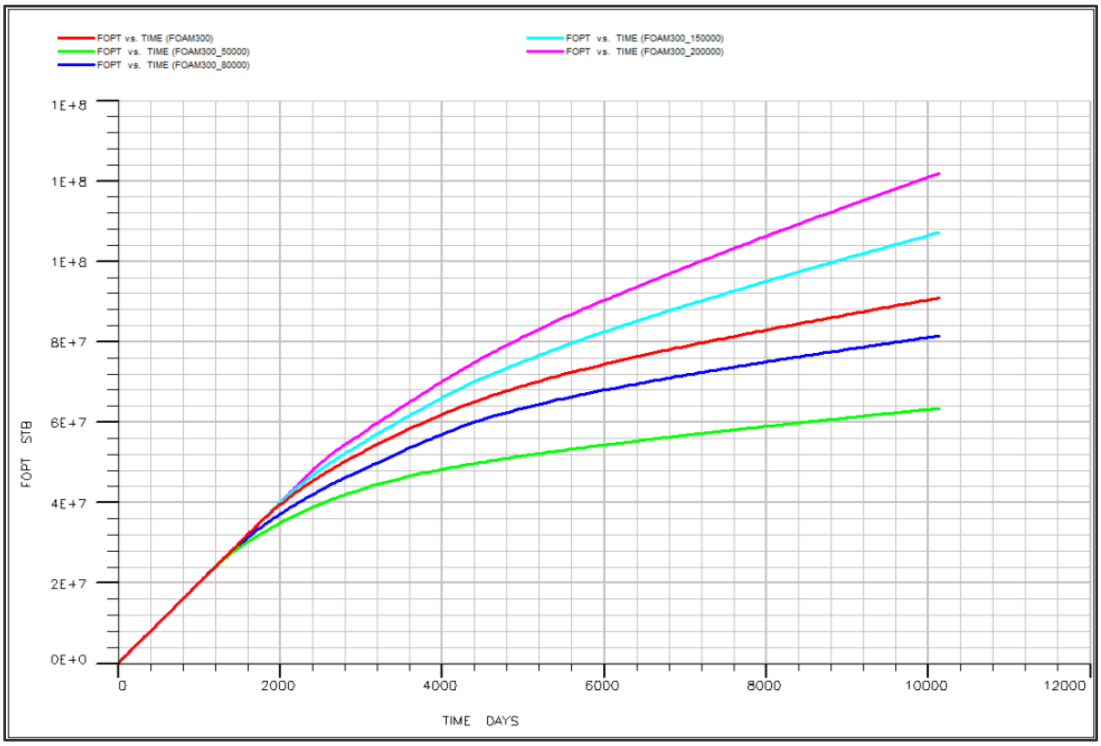


Figure 6: Variation in gas injection rate for FAWAG model without asphaltene

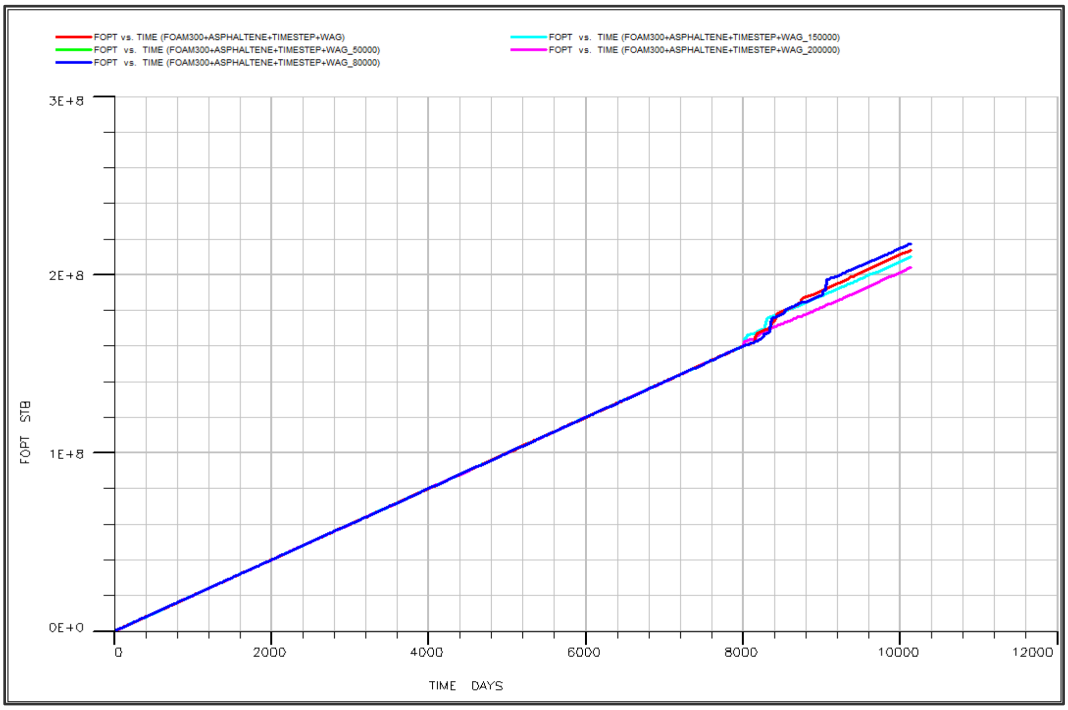


Figure 7: Variation in gas injection rate for FAWAG model with asphaltene

Table 10: Gas injection rate vs FOPT

No.	Gas Injection Rate, scf/day	Field Oil Production Total (FOPT), stb	
		Without Asphaltene	With Asphaltene
1	50,000	6.34E+07	2.14E+08
2	80,000	8.15E+07	2.17E+08
3	100,000	9.09E+07	2.14E+08
4	150,000	1.07E+08	2.10E+08
5	200,000	1.22E+08	2.04E+08

The results of variation in term of gas injection rate for both FAWAG model are represented by Figure 6 and Figure 7. It is observed that in FAWAG model with the absence of asphaltene content gave the highest recovery at the injection rate of 200,000 scf/day. Conversely, at injection rate of 80,000 scf/day in the model with presence of asphaltene gave the highest recovery. There are strong relationship between the injection flow rate and foam dynamics (Al-Mossawy, Birol Demiral, & Raja, 2011). At a higher injection rate, the foam generated will be smaller and the bubble (or foam) sizes will be more uniform. This relationship can be represented as the formula below:

$$\text{Gas Mobility} = \frac{\text{Superficial gas velocity}}{\text{Pressure Gradient}} \qquad \text{---------- Eq. (1)}$$

In the model with absence of asphaltene content, a higher gas injection rate increased the sweep efficiency. The gas which is injected at high rate will produce high quality foam which is small and uniform in size which is able to reduce the gas mobility remarkably (Zhang, Freedman, & Zhong, 2009). Nonetheless, in the model with asphaltene content, the gas injection triggered the precipitation of asphaltene. The deposition of asphaltene on the high permeability zone located at the top layer and the foam generated will prevent the issue of gas early breakthrough. In consequence, the injected gas is forced to travel through the lower permeability zone increasing the sweep efficiency and at the same time achieving the optimum performance at lower gas injection rate.

4.3 Comparison of Water Injection Rate in FAWAG model (without and with)

5000 STB/Day

10000 STB/Day

30000 STB/Day

65000 STB/Day

800000 STB/Day

100000 STB/Day

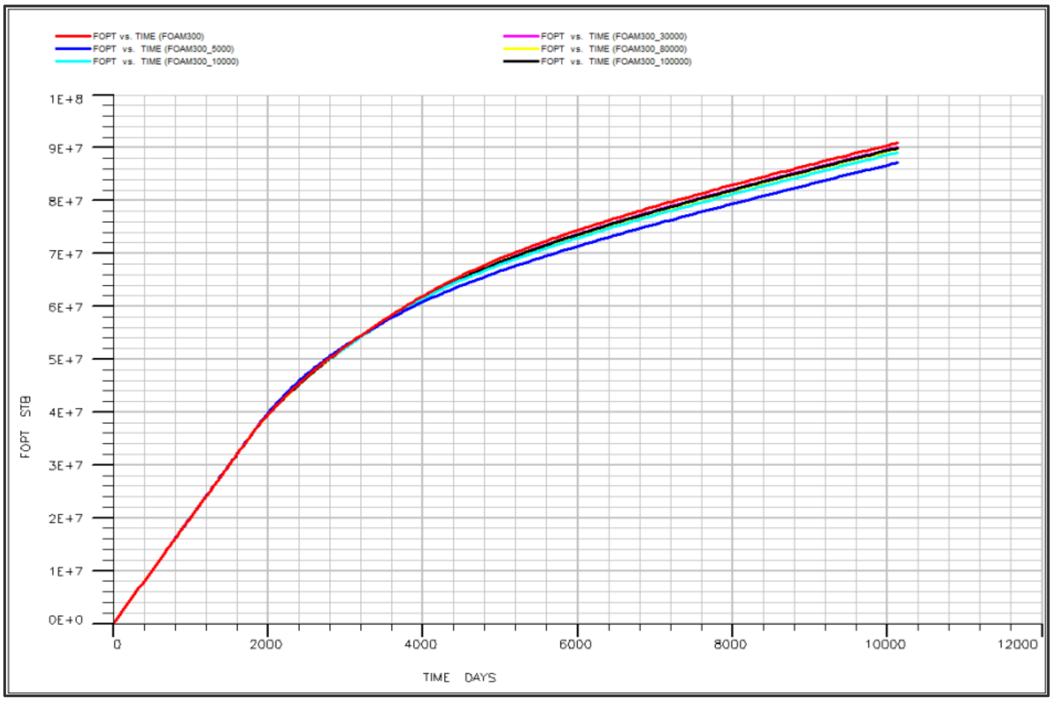


Figure 8: Variation in water injection rate for FAWAG model without asphaltene

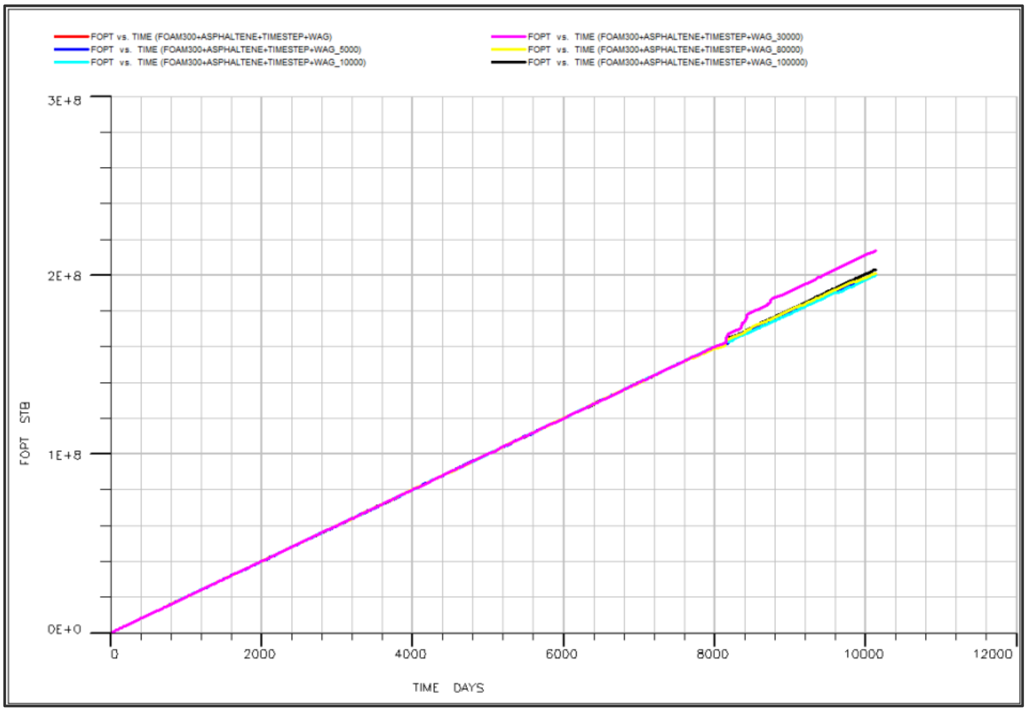


Figure 9: Variation in water injection rate for FAWAG model with asphaltene

Table 11: Water injection rate vs FOPT

No.	Water Injection Rate, stb/day	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	5,000	8.72E+07	2.01E+08
2	10,000	8.91E+07	2.00E+08
3	30,000	9.01E+07	2.14E+08
4	65,000	9.09E+07	2.14E+08
5	80,000	8.97E+07	2.01E+08
6	100,000	8.95E+07	2.00E+08

The results obtained from the simulation runs suggest that FOPT value is sensitive towards the water injection rate. In the case with absence of asphaltene content, the highest FOPT recorded is when the injection rate is 65,000 stb/day and the lowest FOPT is recorded when the injection rate is 5000 stb/day. The water injection rate of 5000 stb/day is too small and is not sufficient to fill pores where the oil is located. Conversely, the injection rate of 100,000stb/day is too high and is not efficient in recovering oil in the reservoir. The high injection rate can cause the displacement front to travel at a high velocity and caused the electrokinetic effect to take place. Electrokinetic effect took place mostly at wellbore where velocity is the highest (Alta'ee A. , 2009). This electrokinetic affect is caused by fluid which stream along with electrical potential. This fluid reacted with asphaltene micelle and resulted asphaltene deposition.

In the case of FAWAG model with asphaltene content, the optimum water injection rate that can be observed from Figure 9 is at 30,000 stb/day and 65,000stb/day. The FOPT value obtained is similar for both of this cases which is the highest among all the cases. However, a further increment in the water injection rate found that the FOPT value is decreased. Increment in the volume of water injection will cause early breakthrough decreases the sweep efficiency and oil recovery (Salehi, Safarzadeh, Sahraei, & S.A.T., 2013).

4.4 Comparison of Surfactant Concentration in FAWAG model (without and with)

0.001 lb/stb

0.01 lb/stb

0.1 lb/stb

0.2 lb/stb

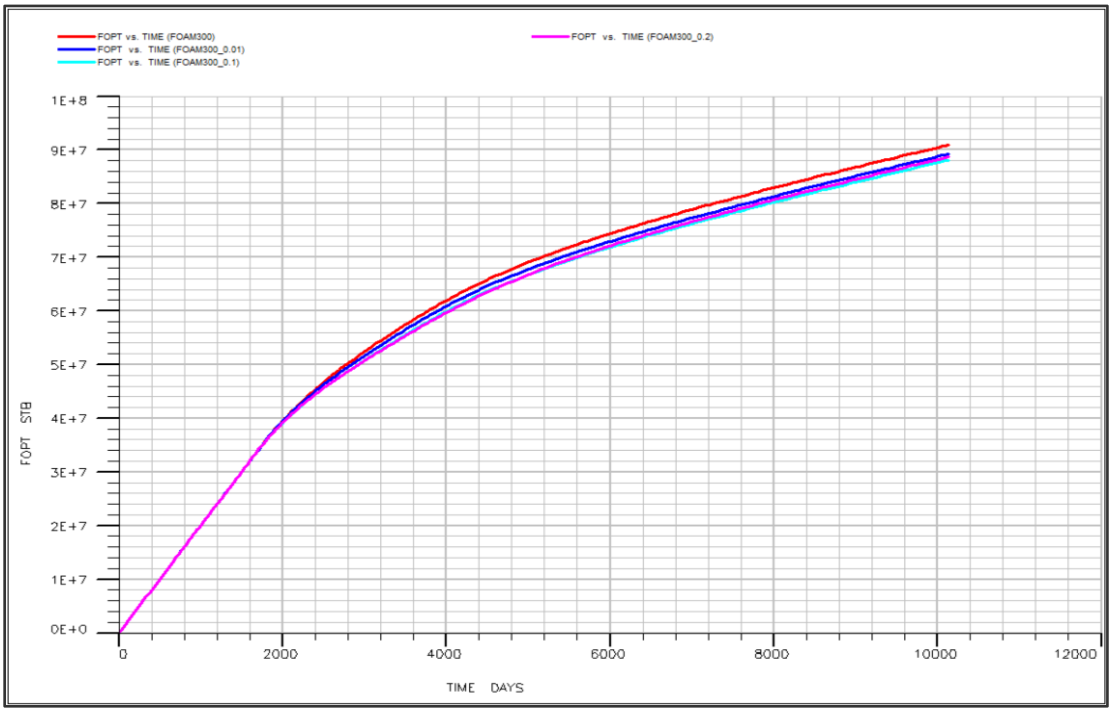


Figure 10: Variation in surfactant concentration for model without asphaltene

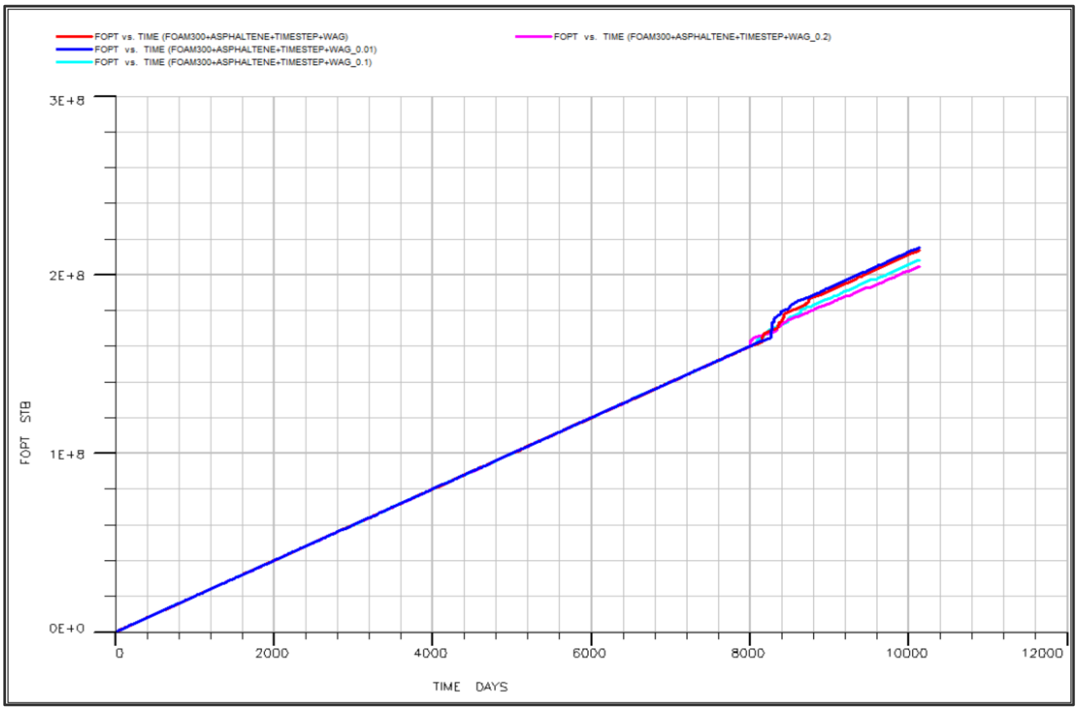


Figure 11: Variation in surfactant concentration for FAWAG model with asphaltene

Table 12: Surfactant concentration vs FOPT

No.	Surfactant Concentration, lb/stb	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	0.001	9.09E+07	2.14E+08
2	0.01	8.92E+07	2.15E+08
3	0.1	8.81E+07	2.08E+08
4	0.2	8.80 E+07	2.05E+08

Simulation runs are carried out using four different concentrations (ranged from 0.01 lb/stb to 0.2 lb/stb) of surfactant. The relationship between concentration of surfactant and the amount of oil recovered is observed. As the result Figure 10 and Figure 11 suggest, there is a relationship between the surfactant concentration and the FOPT. The highest FOPT is observed when the surfactant concentration is 0.001 lb/stb in FAWAG model with absence of asphaltene. On the other hand, the FAWAG model with presence of asphaltene showed that at surfactant concentration of 0.01 lb/stb gives the highest FOPT.

Surfactant used in FAWAG model helps in reducing the interfacial tension between oil and water, generate foam which would provide gas mobility control and in some cases change the wettability of the rocks (Ayirala, Vijapurapu, & Rao, 2006). This series of changes will increase the oil recovery from the reservoir. In both of the FAWAG model, the surfactant concentration which provides the highest recovery will be the optimum concentration where the gas injected is fully utilized in generating foam. This optimum surfactant concentration is also known as critical micelle concentration (CMC). The surfactant concentration that goes beyond or below this CMC will reduce the oil recovery. Moreover, a high surfactant concentration will lead to adsorption causing loss of surfactant solution besides increased the cost of FAWAG operation (Tsau, Syhaputra, Yaghoobi, & Grigg, 1999; Somsundaran & Zhang, 2006).

4.5 Comparison of WAG Ratio in FAWAG model (without and with)

1:0.65

1:1

1:2

2:1

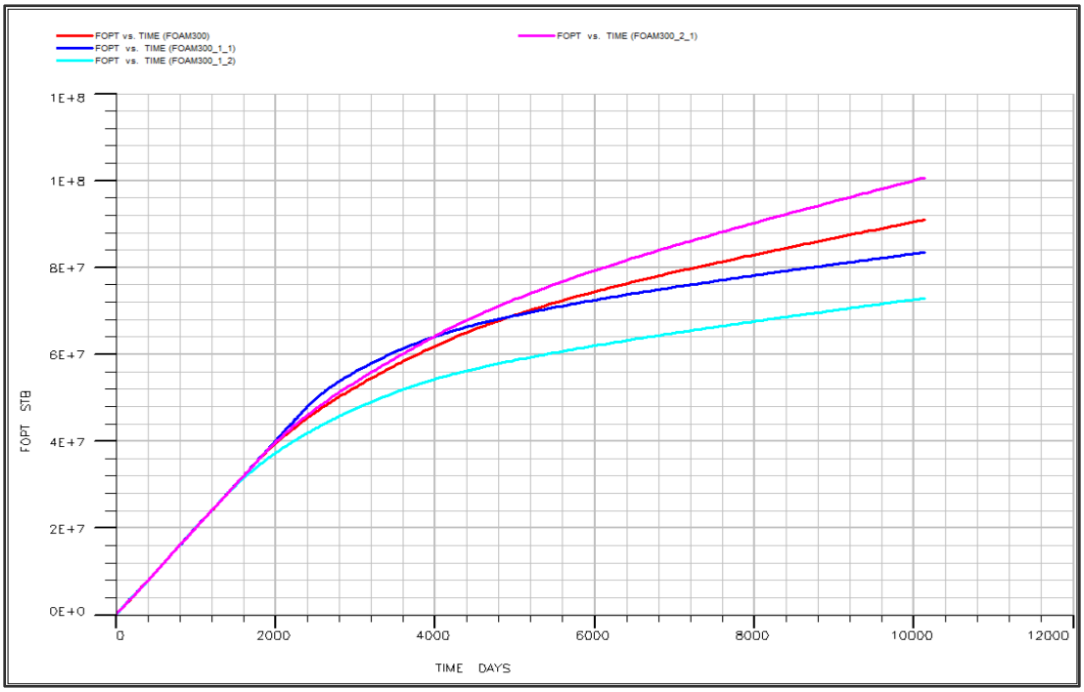


Figure 12: Variation in WAG ratio for FAWAG model without asphaltene

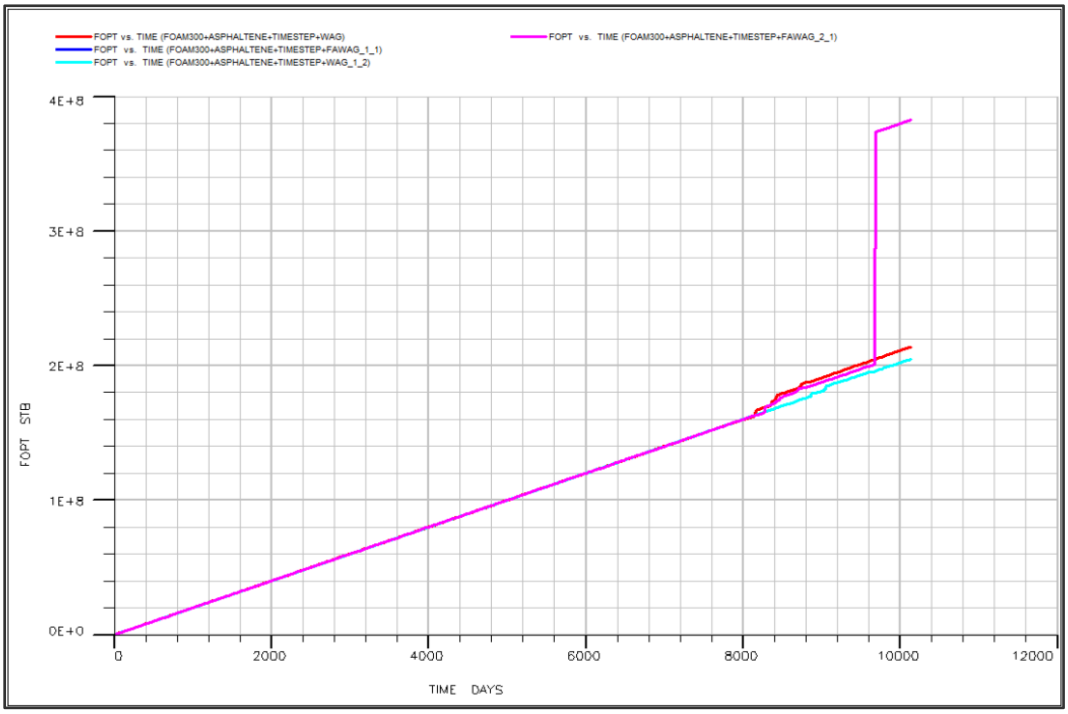


Figure 13: Variation in WAG ratio for FAWAG model with asphaltene

Table 13: WAG ratio vs. FOPT

No.	WAG Ratio	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	1 : 0.65	9.09E+07	2.14E+08
2	1 : 1	8.34E+07	2.13E+08
3	1 : 2	7.29E+07	2.10E+08
4	2 : 1	1.01E+08	3.82E+08

Figure 12 and Figure 13 shows the relationship between WAG ratio and FOPT. In both FAWAG model, it is observed that WAG ratio of 2:1 yields the highest recovery while the WAG ratio of 1:2 yields the least FOPT. In the process of FAWAG injection, surfactant is added into the water forming surfactant solution. When this surfactant solution come in contact with the gas injected, foam will formed. The foam generated improved the gas mobility control by occupying high permeability zones in the reservoir and forcing the injected gas to travel to the lower permeability zones (Salehi, Safarzadeh, Sahraei, & S.A.T., 2013). WAG ratio of 2:1 perform the best out of the other four scenarios as the high water-surfactant injection will optimize the gas injected by enveloping the gas into foam. Furthermore, high water-surfactant solution will help to increase the stability of foam in addition to prevent it from collapsing.

Nevertheless, in the FAWAG model with asphaltene content, a sudden spike is observed at the time of 9600 days. This sudden fold increment in term of oil recovery is due to wettability reversal of rock formation in the reservoir. The wetabillity of the formation can be altered by using surfactant which will leads to higher oil recovery (Austad & Milter, 1997).

4.6 Comparison in WAG Cycle for FAWAG model (without and with)

30:70 days

50:50 days

70:30 days

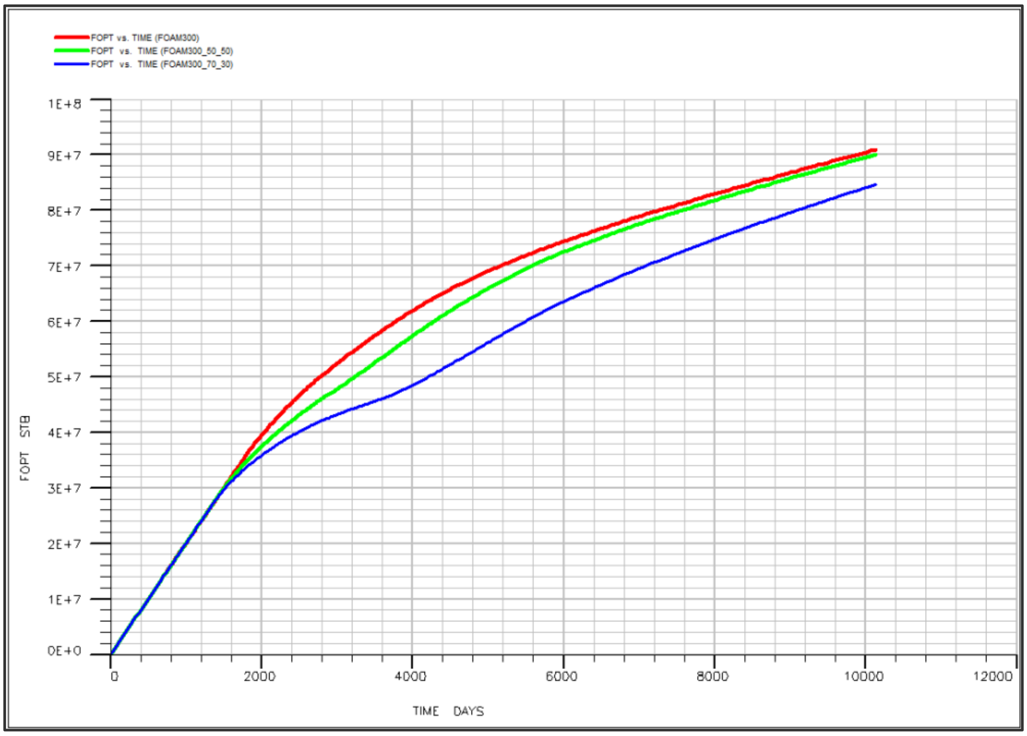


Figure 14: Variation in cycle time for FAWAG model without asphaltene

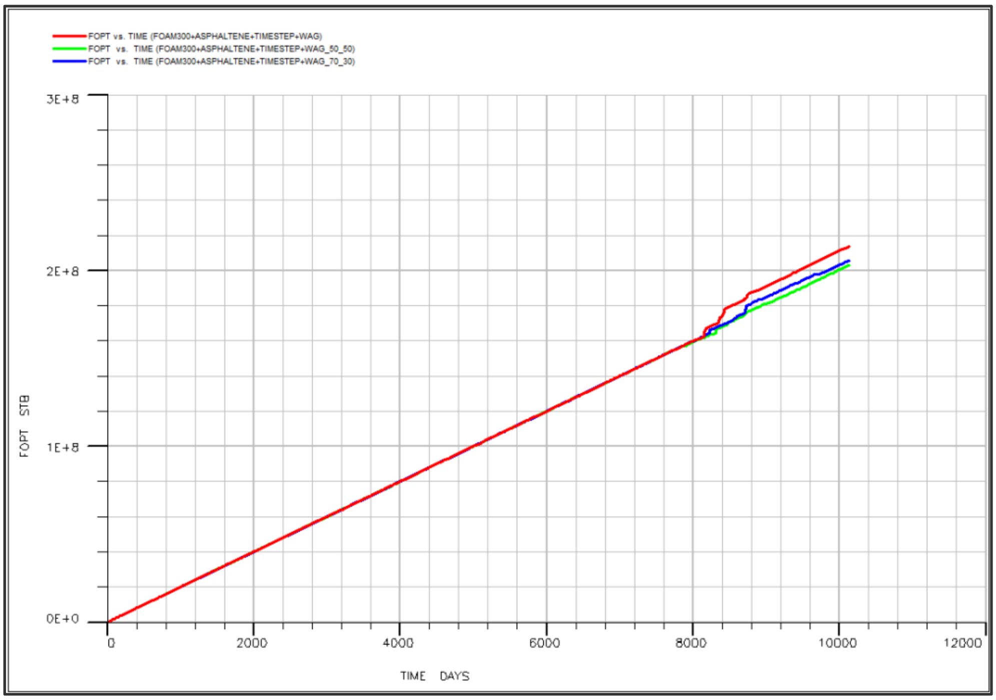


Figure 15: Variation in cycle time for FAWAG model with asphaltene

Table 14: WAG cycle vs. FOPT

No.	WAG Cycle Time, days	Field Oil Production Total (FOPT), stb	
		Withthout Asphaltene	With Asphaltene
1	30 : 70	9.09E+07	2.13E+08
2	50 : 50	9.00E+07	2.03E+08
3	70 : 30	8.46E+07	2.06E+08

Figure 14 and 15 shows the FOPT obtained with variation of WAG cycle time for both FAWAG model either with absence or presence of asphaltene content. It is observed that in both FAWAG model, a 30 days of water-surfactant injection followed by 70 days of gas injection gives the highest FOPT. This is then followed by the 50:50 days WAG cycle and lastly the 70:30 WAG cycle.

An increase in the water-surfactant solution injection will cause reduction in term of recovery (Salehi, Safarzadeh, Sahraei, & S.A.T., 2013). This pro-longed water-surfactant injection cycle time will results in unwanted water-surfactant breakthrough in producing stream. In contrast, the pro-longed gas injection cycle time will be utilized in generating quality foam which aid to control the mobility of gas in the reservoir.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

1. FAWAG technique in the presence of asphaltene give a higher FOPT as the foam generated provides a better gas mobility control. The precipitation of asphlatene on the high permeable zone will forced the gas injected to travel to the lower permeability zone increasing the sweep efficiency.
2. High gas injection rate is required to in order to yield more FOPT in the FAWAG model with absence of asphaltene due to increased quality and durability of foam.
3. The optimum water injection rate is observed to be lower in FAWAG model with presence of asphaltene. Increment in the water injection rate will reduced the FOPT and cause possible early breakthrough of the water-surfactant solution.
4. High surfactant concentration reduced the FOPT in both FAWAG model. Adsorption of surfactant will occur when surfactant concentration above the critical micelle concentration is used.
5. In both FAWAG model with and without asphaltene, WAG ratio of 2:1 work the best and provide the highest FOPT. Optimum water-surfactant to gas injection ratio ensure gas injected is fully utilized to generate foam for mobility control purpose.
6. WAG cycle made up of 30 days of water-surfactant injection followed by 70 days of gas injection gave the highest FOPT by controlling the amount of surfactant injected to prevent early surfactant solution breakthrough and under-utilized the gas injected.

It is recommended that future works should cover more FAWAG parameters such as salinity, injection pressure and type of surfactant. In addition, the simulation of FAWAG should be carried out on a more heterogeneous synthetic reservoir to study the effect of FAWAG in the presence and absence of asphaltene in detail. Laboratory study also should be carried out with the aim of verifying the result obtained for this simulation work.

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